Title of Investigation:

Algorithm for Rapid Characterization of Lunar and Planetary Soils

Principal Investigator:

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Other External Collaborators:

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Initiation Year:

FY 2005

Funding Authorized for FY 2005:

$3,000

Actual or Expected Expenditure of FY 2005 Funding:

Equipment purchase: $1,719.23

Status of Investigation at End of FY 2005:

FY 2006 DDF extension granted

Expected Completion Date:

September 2006

Purpose of Investigation:

Many of the future, currently planned Mars and lunar-lander missions are expected to be capable of digging into their landing sites' surfaces to study and to characterize surface and sub-surface material. To perform this task properly, the landers will need to carry an imager that can image soil material at many different distances to document and monitor trench-digging activity.

For instance, the next Mars lander mission—the 2007 Phoenix lander—has a robotic arm (RA), equipped with a robotic arm camera (RAC) that will be used to dig into the Martian surface to a depth of approximately 1 meter (see Figure 1). To monitor the trench-digging activity at all phases, the RAC has a variable-focus capability so that objects located close to the camera (about 10 mm) and out to infinity can be sharply imaged. Figure 2 shows the RAC's various object planes overlaid on the RA scoop. If the proper image-processing algorithms exist, this imaging capability can quickly discern the bulk soil material properties at the landing site and enable fast decision-making by mission planners.

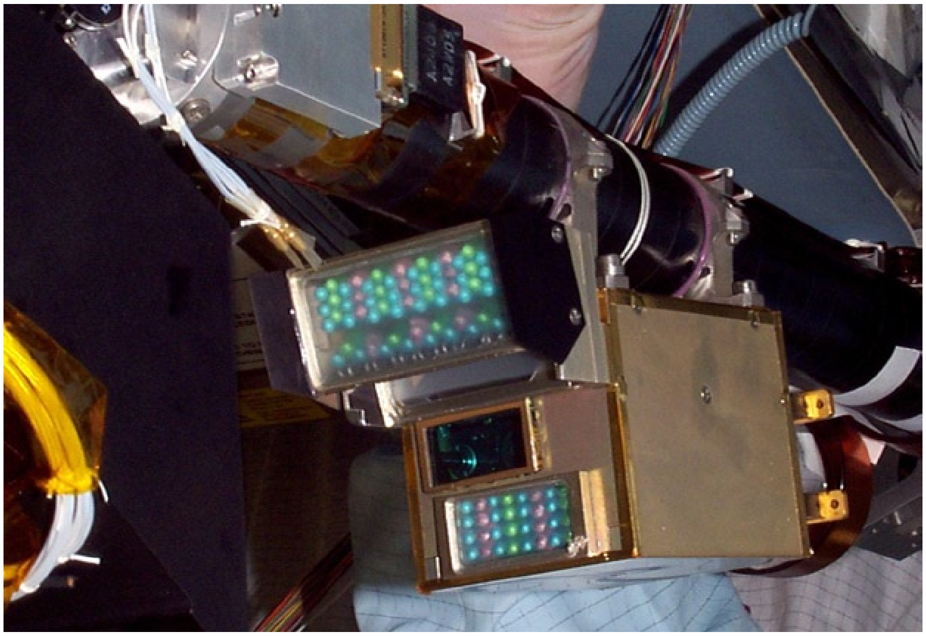

Figure 1. Phoenix lander robotic arm camera mounted on the robotic arm.

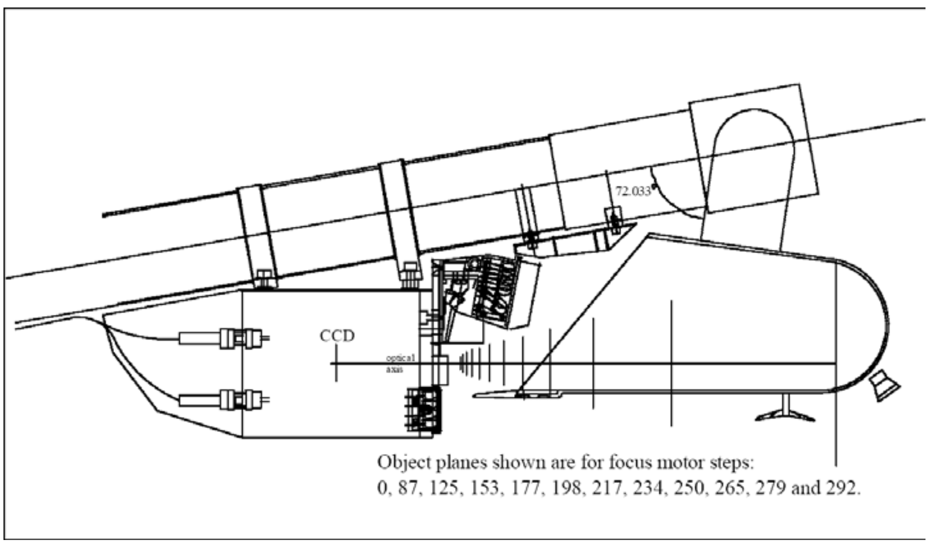

Figure 2. RAC in-focus object planes for various focus motor positions, at motor step 306 the focus extends to infinity

Ideally, during a planetary lander mission, one would like to be able to carefully analyze all the planetary surface material that is excavated by a robotic arm. Unfortunately, however, a lander mission is working with a relatively short and finite lifetime. Therefore, operational decisions must be made quickly on a daily basis so that a lander can operate at peak efficiency. In the particular case of the Phoenix lander, the primary objective is to dig down as quickly as possible to find and to measure Martian sub-surface water.

Two material characteristics that can quickly reveal a great deal about bulk surface material properties are a material's angle of repose and maximum angle of stability. Those two material properties depend on particle size, particle shape and particle moisture. If a lander has the capability to dig and image surface material at multiple distances, then measuring the two characteristic material angles can be done quickly and easily for each scoop of material that is excavated. The images returned from such an experiment could be analyzed manually, but typically there is not enough time to complete all of the analyses desired during mission operations.

To aid the automatic measurement of material properties during planetary-lander missions with architectures similar to the Phoenix lander, we have begun the development of an algorithm that automatically analyzes a series of Phoenix RAC images and automatically detects the distances to objects within the scene. This automatically creates a 3-dimensional map. Figure 3 shows the operation of the algorithm on four RAC images taken at different focus motor steps, producing a single composite image and focus map. The focus map can be used along with the Phoenix RA angular position information to calculate the material angles of interest. The results of a simulation for such an experiment are shown in Figure 4. Performing such a measurement manually with the images could take an hour or more, while the algorithm operation and user interaction only takes a few minutes.

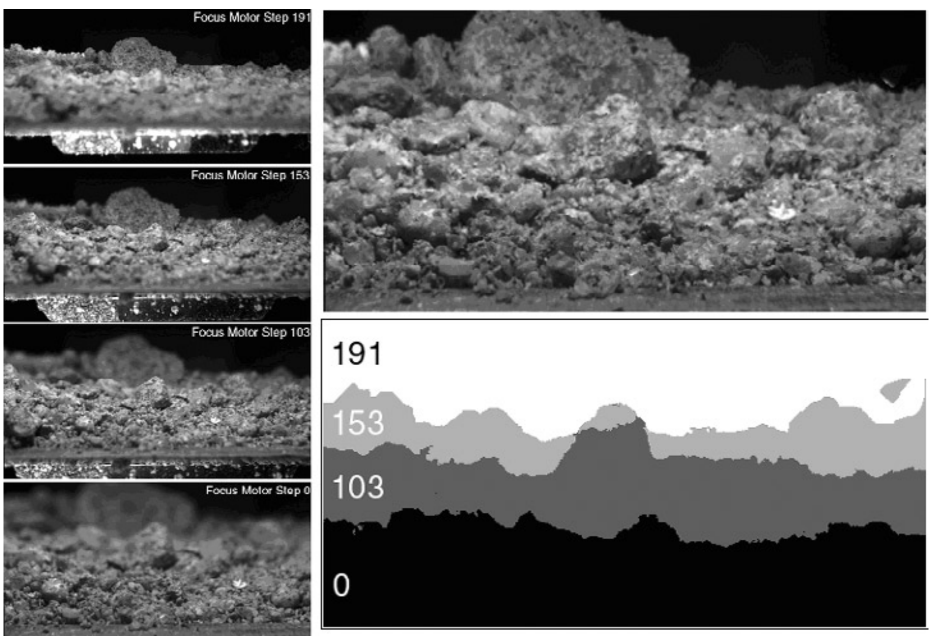

Figure 3. Algorithm processing of 4 RAC images

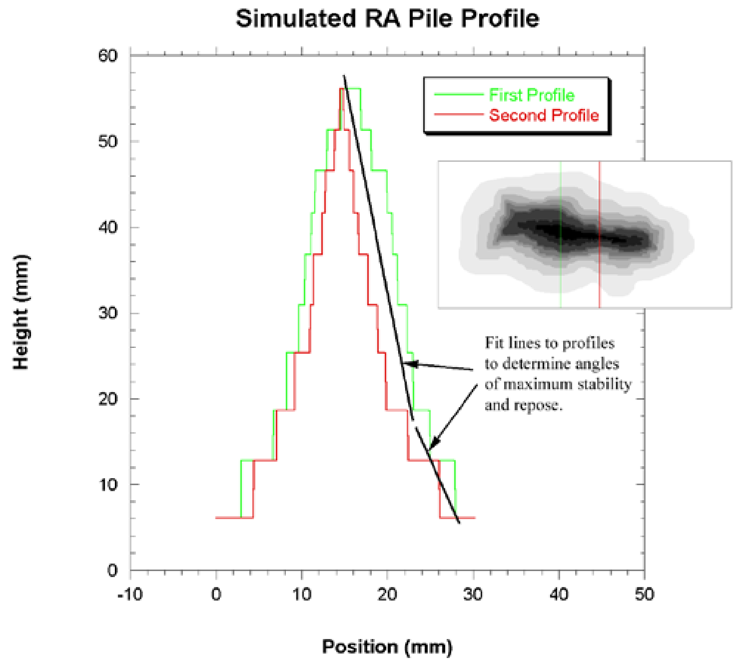

Figure 4. Illustration of the algorithm's focus map being used to calculate the angles of interest

The purpose of this work is to continue the development of the algorithm logic using images of realistic Martian surface excavations captured with the flight spare Phoenix RAC. Such images will be acquired in the University of Arizona Phoenix test bed which is a multi-million dollar facility created to simulate Phoenix lander operations on the frozen Martian surface. When completed, the facility will be similar in appearance to the Mars Polar Lander test bed built in 1999 at UCLA (see Figure 5) but will be an even higher fidelity simulation.

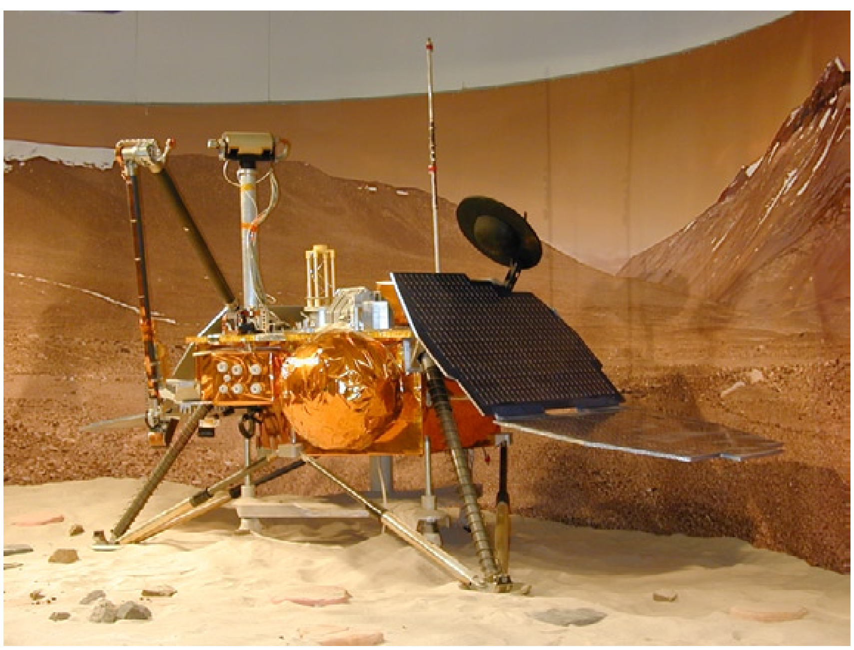

Figure 5. The Mars Polar Lander testbed

Accomplishments to Date:

Because the Phoenix testbed will not be completed until mid-2006, a majority of the proposed algorithm development was delayed. Consequently, the principal investigator traveled to Tucson, Arizona, to construct a miniature RAC and RA-forearm testbed so that a broad set of RAC images of scenes with known angles of repose could be acquired. This was completed in late-April 2005. Figure 6 shows the RAC imaging material in the RA scoop and Figure 7 shows the RAC imaging a pile of soil poured out by the RA scoop.

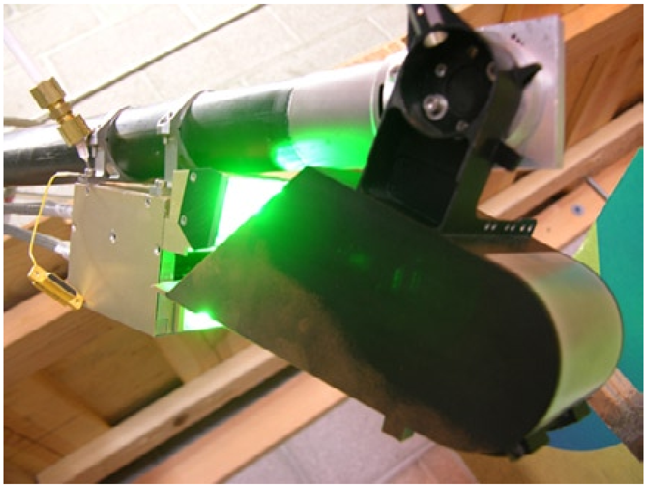

Figure 6. RAC imaging the RA scoop contents

Figure 7. RAC imaging the pile created by the RA scoop

Development of the algorithm logic is continuing using the RAC images acquired in the miniature testbed. The best algorithm logic developed to date is shown schematically in Figure 8, but we anticipate changes will be made to it once more realistic images are acquired using the full Phoenix testbed.

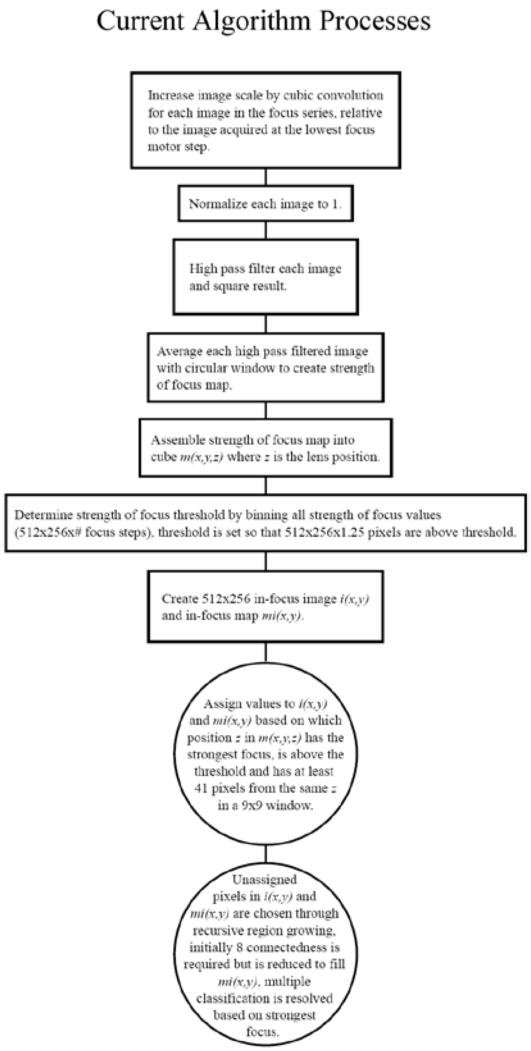

Figure 8. Current algorithm logic flow

Our most important finding to date is the discovery that the RAC depth of focus for focus motor steps 292-212 is too large to provide depth information for RAC to object distances of 107 mm and greater. This will make it difficult to measure the angles of repose of piles created by the RA scoop. The RAC will need to be positioned to within 107 mm of a pile to make the angle-of-repose measurement with the proposed algorithm. If this cannot be safely accomplished, then the RAC will only be capable of making the material angle measurements for objects located within the RA scoop. Alternative approaches using stereo imaging with the RAC or the Phoenix Surface Stereo Imager (SSI) may still make it possible to make the desired measurements on the RA scoop piles.

Planned Future Work:

With the project extension granted by the DDF program, we will be pursuing the original goals of the algorithm research in FY 2006. We expect to be able to improve the algorithm logic using images acquired from the high-fidelity Phoenix testbed. And we will be exploring further the measurement errors in the angles of repose and maximum stability measurements derived from the RAC images and the algorithm.

Key Points Summary:

Project's innovative features: This is the first algorithm we are aware of to make angle-of-repose and angle-of-maximum stability measurements from a spacecraft imager.

Potential payoff to Goddard/NASA: Successful completion of this research will benefit NASA's Phoenix Mars mission and other lander-imager projects in which Goddard participates.

The criteria for success: We will consider the effort successful when we demonstrate, with RAC images from the Phoenix testbed, the algorithm's ability to calculate angles-of-repose and maximum stability to an accuracy of approximately ±5°.

Technical risk factors: As previously described, the RAC's imaging performance ultimately may be the critical factor that limits the algorithm's functionality—not the algorithm itself. Since the RAC images are provided free-of-charge to us by our University of Arizona collaborators, and this project cannot afford to improve the camera's performance, it is a risk we have to accept. There also is a chance that the completion of the Phoenix testbed may be delayed again due to Phoenix program budget shortfalls, but that, too, is beyond our control.